

THE EXPOSURE HISTORY OF JILIN AND PRODUCTION RATES OF COSMOGENIC NUCLIDES; G. Heusser, Max-Planck-Institut f. Kernphysik, POB 103980, D-6900 Heidelberg, Germany

Jilin the largest known stone meteorite is a very suitable object for studying the systematics of cosmic ray-produced nuclides in stony meteorites. Its well established two stage exposure history (1,2,3) even permits to gain information about two different irradiation geometries (2π and 4π).

All stable and long-lived cosmogenic nuclides measured in Jilin so far correlate well with each other (3,4,5). An example is shown in Fig. 1 where the ^{26}Al activities are plotted vs. the spallogenic ^{21}Ne concentration (6,7).

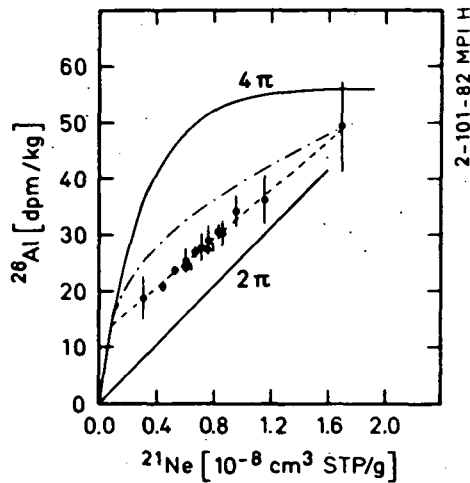


Figure 1: ^{21}Ne - ^{26}Al correlation in Jilin and its evolution from a 2π irradiation geometry followed by a 4π irradiation geometry. ^{21}Ne from (6,7).

These records of cosmic-ray interaction in Jilin can be used both to determine the history of the target and to study the nature of production rate profiles. This is unavoidably a bootstrap process, involving studying one with assumption about the other.

The good correlation (dotted line in Fig. 1) with a positive ordinate intercept is interpreted in terms of a 2π irradiation followed by a 4π irradiation.

The production of stable (S) and radioactive (R) nuclides by cosmic rays in a large body (2π geometry) can be described by:

$$S(d) = P_S(d) t \quad (1)$$

$$R(d) = P_R(d) (1 - e^{-\lambda t}) \quad (2)$$

where $P_S(d)$ and $P_R(d)$ are the depth-dependent production rates of the stable and radioactive species, respectively and t is the exposure time. Both expressions can be combined:

$$R(d) = \frac{P_R(d)}{P_S(d)} \frac{1 - e^{-\lambda t}}{t} S(d) \quad (3)$$

For a given t and a constant production rate ratio $P_R(d)/P_S(d)$ this is the equation of a straight line $R=m \cdot S$ through the origin (solid line labelled 2π in Fig. 1). Its slope is determined by the production rate ratio and the duration of exposure.

For a 4π irradiation with negligible depth effects for the production of spallogenic nuclides as indicated by the measured ^{22}Na activities in Jilin (3) the production equations

$$R = P_R(1 - e^{-\lambda t}) \text{ and } S = P_S t$$

represent the curve of growth in the R vs. S diagram (Fig. 1, labelled 4π)

G. Heusser

$$R = P_R(1 - e^{-\lambda \frac{S}{P_S}}) \quad (4)$$

If a 2π irradiation is followed by a 4π irradiation, the relevant production rates are expressed by:

$$S(d) = P_{S1}(d)t_1 + P_{S2}t_2 \quad (5)$$

$$R(d) = P_{R1}(d)(1 - e^{-\lambda t_1}) e^{-\lambda t_2} + P_{R2}(1 - e^{-\lambda t_2}) \quad (6)$$

where P_1 and P_2 are the production rates of the first (2π) stage and the second (4π) stage, respectively and t_1 and t_2 are the respective exposure ages. Again with the assumption of a constant production ratio we get:

$$R(d) = \frac{P_R(d)}{P_S(d)} \frac{1 - e^{-\lambda t_1}}{t_1} e^{-\lambda t_2} S(d) + P_{R2} \left\{ 1 + \frac{t_2}{t_1} e^{-\lambda t} - \frac{t}{t_1} e^{-\lambda t_2} \right\} \text{ with } t = t_1 + t_2 \quad (7)$$

For t_1 and t_2 fixed equation 7 is the equation of a straight line of the form $R = mS + b$ with slope

$$m = \frac{P_R(d)}{P_S(d)} \frac{1 - e^{-\lambda t_1}}{t_1} e^{-\lambda t_2} \quad (8)$$

As t_2 increases for t fixed, the intercept of the original 2π straight line is shifted upwards along the curve of growth while its slope is decreasing. The fit line through the data points obtained for Jilin (dotted line in Fig.1) illustrates this behaviour. The straight line and the curve of growth intersect at

$$R_{\text{inters.}} = P_{R2}(1 - e^{-\lambda t_2}) \quad (9)$$

Hence t_2 can be calculated if P_{R2} is known. We can then enter the value of t_2 into equation (8) and obtain t_1 by iteration, provided that we know the production rate ratio. With well founded assumptions about the individual production rates eq. (9) yields $t_2 = 0.4$ Myr and eq. (8) $t_1 = 9$ Myr (3). If the stable isotope is replaced by a long-lived radionuclide, the general equation of the correlation line has the form:

$$R_A(d) = \frac{R_A}{R_B} \frac{e^{-\lambda_A t_2} - e^{-\lambda_A t}}{e^{-\lambda_B t_2} - e^{-\lambda_B t}} (R_B(d) - P_{A2} + P_{A2} e^{-\lambda_B t_2}) + (1 - e^{-\lambda_A t_2}) P_{A2} \text{ with } t = t_1 + t_2. A \text{ is the radionuclide with the shorter half life.}$$

THE EXPOSURE HISTORY OF JILIN...

G. Heusser

Accepting the nature of Jilin's exposure history, we can now turn to the information provided by these correlations in view of production rate ratios and individual production profiles. The perfect straight line fit of the data points (Fig.1) confirms our assumption of a constant production ratio (eq. 3, 7, and 8), i.e. the production rate of ^{26}Al must have a depth dependence very similar to ^{21}Ne . The sensibility of this behaviour is illustrated as an example for the case that the mean half thickness of ^{21}Ne is twice that of ^{26}Al . The calculation was normalized for the highest data point. The resulting correlation (point-dotted curve in Fig.1) corresponds to a bend curve which is very distinct from the straight line formed by the experimental points. In this way, the depth dependence of production rates of other long-lived and stable cosmogenic nuclides could be investigated in Jilin as well.

References

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